MEASUREMENT OF AERODYNAMIC ROUGHNESS USING RADAR BACKSCATTER OVER VEGETATED SURFACES

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ABSTRACT

Measurement of wind fields is important for many reasons. Wind regime data can be used to infer the amount and type of wind-induced (aeolian) transport of sand and dust, or to establish global circulation models, for example on other planets. Since local measurements are costly and often impossible, it is desired to infer such data from remotely-sensed information. This paper describes a potential mechanism for remotely inferring the wind regime by using synthetic-aperture radar data to describe the roughness of the surface, and describes a project to estimate the practicality of using such a mechanism. An experiment is reported that extends the. mechanism to vegetated sites, where the goal is to measure potential for erosion.

KEY WORDS: Roughness, Wind, Aeolian Processes, Radar, Vegetation

INTRODUCTION

Aeolian transport of small particles depends on wind flow and is an important quantity to measure for several economic-related reasons. The direct measurement of wind flow regime generally involves construction of wind towers and many days of data collection, making such data extremely expensive and prohibitive in areas that cannot be easily accessed. If some estimate of wind regime could be made from remotely-sensed data, important geological and ecological problems on Earth and other planets could be addressed. Indeed, qualitative use has been made of radar wind streaks on Venus to assess the direction of wind flow and to infer global wind patterns [Greeley *et al.*, 1992], but the addition of quantitative information would be a welcomed addition.

The effect of roughness on the wind field is parameterized in terms of a scaling length that, for a given surface, determines the height at which the wind speed becomes zero. Since in fact the wind speed never reaches zero even at the surface, a more practical parameter is the height at which extrapolation of the wind speed reaches zero, generally represented by z_0 [*Arya*, 1982]. Microwave reflectivity is a function of the radar parameters used (e. g., wavelength, incidence, angle, and transmit and receive polarization) and the surface properties (surface topography and complex dielectric constant), For modest topography and typical materials, the roughness at or near the radar wavelength dominates [*Blom et al.*, 1987; *Wall and VanZyl, 1989*].

Since both radar and wind flow respond directly to surface roughness, it is reasonable to suspect that a fairly well-behaved quantitative relationship might exist between normalized radar backscatter coefficient, σ^o, and z_0 [*Ulaby et al., 1992*]. Of course, the scales of topography that affect the wind are much broader, and only if the target area contains no roughness at scales significantly greater than the radar wavelength could the relationship be expected to hold dependably. In fact, however, estimations of z_0 from wind profile data also require a large homogeneous fetch in order to assure that measurements are taken within an equilibrium boundary layer.

The Radar and Aeolian Roughness Project (RARP) has been formed in order to investigate whether such a relationship exists, to determine the relationship(s) over a variety of surface types, and to seek a theoretical basis from which to extend the relationship to surfaces that cannot be directly examined [*Greeley et al., 1991a*]. We have collected wind data using towers instrumented with anemometers in both desert and vegetated areas, and have

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overflown these same sites with the NASA IX-8 aircraft fitted with AIRSAR, a three frequency, polarimetric SAR developed by JPL operating at P, 1. and C bands [*Evans et al., 1986; Vogt, and Kobrick, 1991]*. Multiple overflights of each silt created a data set from which σ^o can be calculated at multiple incidence angles, frequencies and polarizations. In previous reports wc have shown that in desert areas L-band (24-cm wavelength), cross-polarized (} IV) radar backscatter taken at an incidence angle of 40 degrees demonstrates the bcsl-behaved relationship to z_0 [*Greeley et al., 1991 b*]. Desert sites were chosen on lava flows, alluvial fans dominated by sand and gravel of differing ages and roughnesses, and on a silt-clay playa. l'here, roughness varied from a fcw cm to a fcw tens of cm, although rills and small washes 1 to 2 m wide were common, All sites were unvegetated with the exception of occasional creosote bushes in the washes and isolated patches of grasses. Signs of active sand transport and in some cases of abrasion, were evident.

Wc decided to compare this relationship to data from vegetated sites where wind erosion is a potential problem. In the desert sites surface roughness has two components: (1) size and arrangement of surface particles and (2) submeter-scale roughness of the surface. Vegetation adds not only the complication of a third factor (the ncw surface consisting of the stems, branches, and leaves), but also adds a possible new interaction mechanism because the surface is now "thick"; that is, it is at least partly penetrable by both microwaves and the, wind. In the case of microwave energy, this adds the possibility of mulliplc-bounce geometries which lend to depolarize the returned energy. In the case of the wind the effect is far less clear.

A site near the village of Stauning, Denmark, in the river Skjern delta area near Ringkobing Fjord, has been equipped with meteorological instruments for some time and was selected for study. The area is agricultural, including a variety of tree and crop types. Of the eight areas selected for this study, seven were sewn in various crops (*e.* g., barely, rape, beet, peas and grasses), and one is a stand of Spruce trees. Vegetation height varies from tens of centimeters to several meters, and the corresponding roughness lengths arc z_0 = 0.02 to 0.75 [*Rasmussen et al., 1993*]. Unlike the desert sites of the previous study, here all sites were essentially 100% vegetated. However, evidences of active aeolian transport were, present, and 0.5 to 1 cm low rills were observed with spacing of 5-10 cm or larger.

DATA COLLECTION

The DC-8 overflight was organized and executed in July 1991. The AIRSAR obtains data al three wavelengths simultaneously with 12.5 m resolution, but multiple flights over targets arc required to assemble a multip]c-angle data set. Radiometric calibration accuracy of the. resulting images is estimated al+/- 3 dB [*VanZyl, 1990*]. Denmark targets, including the Stauning silt, were imaged at multiple incidence angles near 1400 UT. A set of trihedral corner reflectors placed on the North Sca coast was also imaged to ensure radiometric calibration of the data. Images such as that shown in Figure 1 were produced from the AIRSAR data, and radiometric calibration was checked using the known response of the corner reflectors. Eight areas for which z_0 is known or could bc inferred from field work were identified in the images.

Soil moisture samples were taken from some of the sites, and local observations were recorded. All sites had volumetric moisture content near 30%. Contemporary meterological data were obtained at the Stauning site, although the z_0 data used in this study is from the larger set of data available for the silt, as described below.

ANALYSIS

Patches representing the eight lest areas were extracted from the data and were averaged in power to create estimates of L-band H V backscatter cross-section. These were compared with the corresponding roughness measures, Estimates were made for all other wavelengths and angles and for H H and VV data but were not used for this study. Polarization signatures were constructed for each site and checked for signs of contamination or other problems, and (with the exception of the P-band data, which was not used here) all data were. Judged to be reliable.

Wind profile data for the Stauning silt arc available from June 1991. Those showing near-neutral thermal stability were used to calculate values of z_0, and these latter data were found to be uniform between 3 to 5 cm at the main silt. }Iot-wire anemometer data were taken at 1.5 m above the surface on three other sites for both morning and afternoons. A proportionality constant of 0.75 was assumed to relate zero-plane displacement to the measured crop

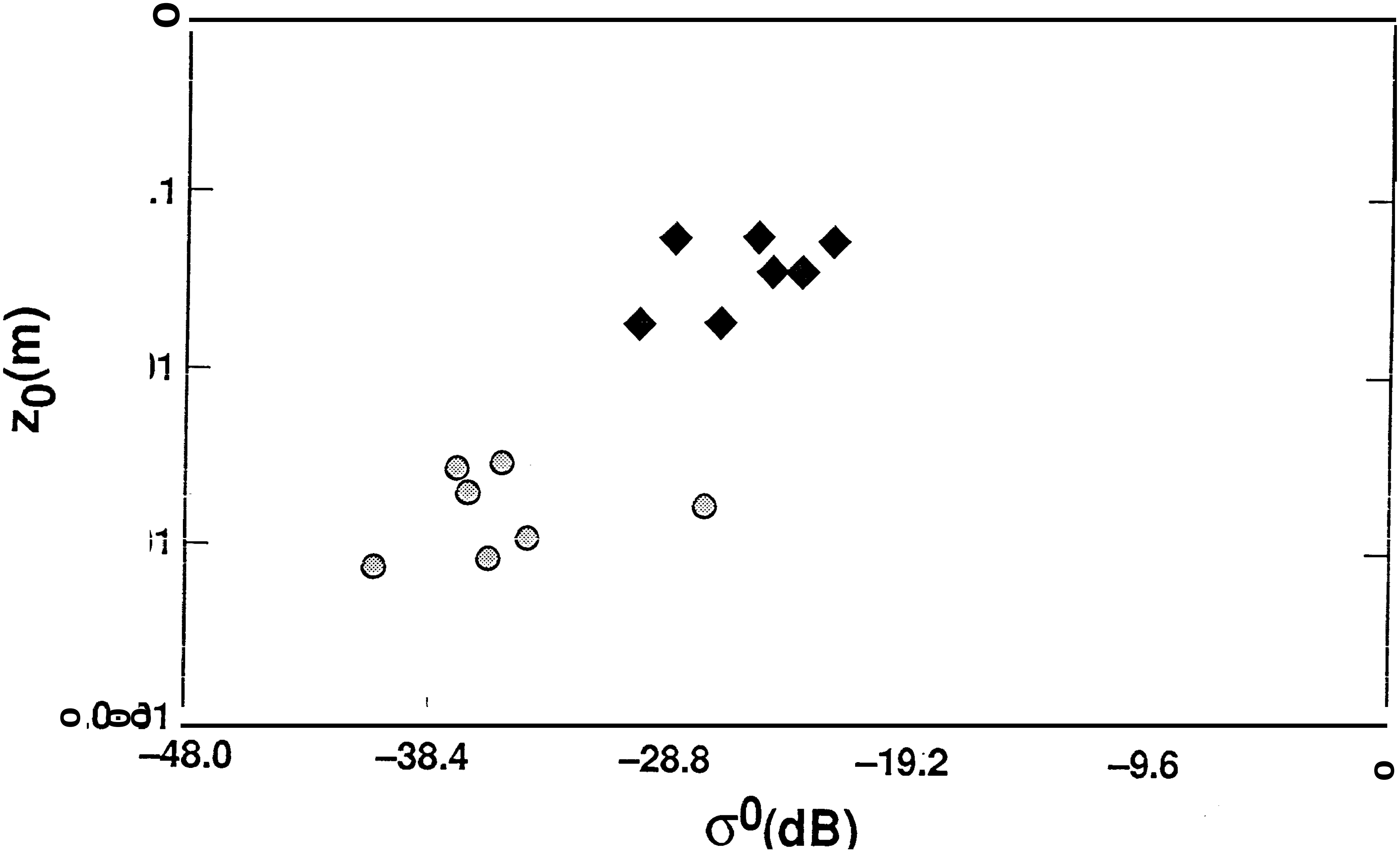

Figure 2. - Values of z and L-band σ^o_{HV} vegetated patches at Stauning (◆) and desert test sites (◎) in Southern California.

height, and these data were used to calculate z_0. At the grass sites no direct measurement of z_0 was available. Instead, values were estimated as suggested by *Brutsaert, 1982*, assuming z_0 = 0.55 }1, where }1 is grass height.

CONCLUSION

The resultant relationship of σ^o to z_0 is plotted in Figure 2 together with our previous desert results, Note that σ^o is plotted in decibels (dR) against log z_0, so the, plot is essential I y a log-log plot of height against returned power. For seven of the vegetated areas (the agricultural fields) the radar backscatter values arc of the same order of magnitude (in dB), and the Spruce site is much brighter. Although all of the. vegetated sites arc both brighter in backscatter and rougher than the previous study, there is an overall good correlation between the two data sets. Coefficient of fit (R^2) is 0.79 for the entire plot.

Wc arc now prepared to continue this study towards our ultimate goal of having a prcdic.live model. First wc will investigate the relationship in the more complicated case of a heterogeneous roughness, with scattered vegetation. Second, wc plan to establish a theoretical basis for the σ^o - z_0 association so that wc may more comfortably extend the empirical relationship into a predictive model.

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